

Requirements and Techniques for Developing and Measuring Simulant Materials. Doug Rickman^{1*}, Charles Owens², Rick Howard³, ¹Marshall Space Flight Center, National Aeronautics and Space Administration, 320 Sparkman Drive, Huntsville, AL 35805 doug.rickman@nasa.gov, ²Teledyne Brown Engineering, Huntsville, AL 35812 charles.e.owens@nasa.gov, ³Teledyne Brown Engineering, Huntsville, AL 35812, rick.howard@tbe.com,

* Corresponding Author

Introduction: The 1989 workshop report entitled *Workshop on Production and Uses of Simulated Lunar Materials* [1] and the *Lunar Regolith Simulant Materials: Recommendations for Standardization, Production, and Usage*, NASA Technical Publication [2] identify and reinforced a need for a set of standards and requirements for the production and usage of the lunar simulant materials. As NASA need prepares to return to the moon, a set of requirements [3] have been developed for simulant materials and methods to produce and measure those simulants have been defined. Addressed in the requirements document are: 1) a method for evaluating the quality of any simulant of a regolith, 2) the minimum characteristics for simulants of lunar regolith, and 3) a method to produce lunar regolith simulants needed for NASA's exploration mission. A method to evaluate new and current simulants has also been rigorously defined through the mathematics of Figures of Merit (FoM), a concept new to simulant development.

A single FoM is conceptually an algorithm defining a single characteristic of a simulant and provides a clear comparison of that characteristic for both the simulant and a reference material. Included as an intrinsic part of the algorithm is a minimum acceptable performance for the characteristic of interest. The algorithms for the FoM for Standard Lunar Regolith Simulants are also explicitly keyed to a recommended method to make lunar simulants.

Benefits for this approach; 1) permit multiple materials to be used as standards; 2) allow multiple simulants to be compared in a standardized manner; 3) allows simulants to be standardized to a definition based on measurement protocols and not restricted to a physical reference material; 4) new batches of simulants or multiple providers of simulants can be readily compared and 5) simulant requirements are permitted to evolve as knowledge or needs change.

Intended Users: The scientific and engineering communities are the primary two intended users of lunar regolith simulant materials.

Utilization of the simulant by the science community will be in small quantities (kilograms vs. metric tons in most cases) in a laboratory or specialized pilot facility with the intent of developing or improving a process (e.g. oxygen or metals extraction) and may only require discrete amounts of simulant. Expectations are that the FoMs for these simulants will have higher values and tighter tolerances banding together to require more closely controlled simulant production. This in turn reflects on the additional quality control aspects of how the simulant materials were collected, processed, and blended, with particular attention to minimizing contamination.

Potential vendors may use offsite analytical techniques to verify the simulant to the FoMs applied. Offsite implies that statistically relevant samples have been taken from the components individually and the simulant after mixing, and analyzed in a laboratory setting to verify the quality of the product. Tighter production tolerances or secondary processing are expected to drive higher dollar/kg costs to the end user.

Utilization of the simulant by the engineering community will be in larger quantities (metric tons) necessary to develop large-scale processes for lunar production facilities and construction. Processes developed for lunar industrial applications must be robust enough to handle small amounts of contamination inherent in the processing of large quantities of rocks and minerals on Earth. Many of these contaminants will be introduced during lunar processing as well. Expectations are that the FoMs for these simulants will have lower values for some characteristics based on their intended end use. Potential vendors may use insite analytical techniques to verify quality of the simulant during production. Insite implies that a continuous sampling and analysis is occurring during the production run. Common methods of measurement utilized in continuous industrial processing are laser diffraction and automated vision systems. Automated analytic techniques coupled with large quantity production are expected to reduce the dollar/kg costs to the end user.

Establishing Requirements Through the Figures of Merit: Based on the work published in the *Lunar Regolith Simulant Materials: Recommendations for Standardization, Production, and Usage*, NASA Technical Publication [2], four key characteristics of the lunar regolith have been initially selected for the Simulant Requirements document. Those characteristics are composition, size, shape and density. As needs change new requirements and FoMs may be added, deleted or modified. To demonstrate the link between a Figure of Merit and requirements the FoM of "composition" may be used as an example.

The Figure of Merit termed "composition" defines the geologic constituents of the simulant without reference to textural features, such as particle shape and particle size. Composition includes the following classes of constituents: lithic fragments, mineral grains, glasses and agglutinates. Conceptually, composition addresses the chemical makeup of individual particles. The simulant requirements document specifies the rock types and their chemical make up, which may or may not be used to establish a simulant requiring this type of Figure of Merit.

Establishing a Reference Material: In normal use a reference material would be defined as a regolith core sample returned by an Apollo mission. However, any material real or predicted may be used, including another simulant. The reference material is measured and assigned values of 1 for all properties to be described by the Figures of Merit. The simulant is measured for the same properties as the referenced material and the differences are evaluated according to the algorithms of the FoMs selected for comparison.

The usefulness of allowing a predicted material to be a reference is that as mission planners evaluate and select potential lunar sites for exploration, existing and new simulants may be evaluated for potential analogs for those sites through the Figures of Merit. If simulants must be produced manufactures of such materials now have a way to measure their product and select the "best fit" raw materials and processing techniques.

Contamination of Simulant Materials: Contaminants can be introduced into simulant materials at any point during their manufacturing and storage, rendering the material useless for some applications. Vapors from nearby solvents or fine particles from nearby construction sites have been known to contaminate and disrupt the manufacture of new simulants. Thus the

Simulant Requirements document addresses this problem and defines the maximum allowable contaminants in a simulant material.

Conclusions: Requirements and techniques have been developed that allow the simulant provider to compare his product to a standard reference material through Figures of Merit. Standard reference material may be physical material such as the Apollo core samples or a predicted material such as a polar landing site. The simulant provider is not restricted to providing a single "high fidelity" simulant, which may be costly to produce. The provider can now develop "coarser fidelity" simulants for engineering applications such as drilling and mobility applications.

References: [1] D. S. McKay, James D. Blacic, *Workshop on Production and Uses of Simulated Lunar Materials*, LPI Technical Report Number 91-01. [2] Sibille L., Carpenter P., Schlagheck R., and French R. (2005) *Lunar Regolith Simulant Materials: Recommendations for Standardization, Production, and Usage*, NASA Technical Publication (in print) [<http://isru.msfc.nasa.gov/lib/workshops/lrsm2005.html>]. [3] Marshall Space Flight Center, *Lunar Regolith Simulant Requirements*, MSFC-RQMT-3503, August 31, 2006.

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